TNO Defence Research

TNO Physics and Electronics Laboratory

Oude Waalsdorperweg 63
2597 AK The Hague
P.O. Box 96864
2509 JG The Hague
The Netherlands

Fax +31 70 328 09 61
Phone +31 70 326 42 21

TD

TNO-report
FEL-93-A043

copy no.

title

Experimental evaluation of camouflage effectiveness in the thermal infrared

AD-A266 290

author(s):

Dr. P.A.M. Jacobs

date:

March 1993

classification

classified by : A.A.M. Aarssen

classification date : February 25, 1993

title : ongerubriceerd

abstract : ongerubriceerd

report text : ongerubriceerd

no. of copies : 30

no. of pages : 27 (excluding RDP and distribution list)

no. of appendices : -

All information which is classified according to Dutch regulations shall be treated by the recipient in the same way as classified information of corresponding value in his own country. No part of this information will be disclosed to any party.
The classification designation ongerubriceerd is equivalent to unclassified

93-14794

report no.	:	FEL-93-A043
title	:	Experimental evaluation of camouflage effectiveness in the thermal infrared
author(s)	:	Dr. P.A.M. Jacobs
institute	:	TNO Physics and Electronics Laboratory
date	:	March 1993
NDRO no.	:	A90KL656
no. in pow '93	:	715.5

Research supervised by:

Research carried out by: Dr. P.A.M. Jacobs

ABSTRACT (ONGERUBRICEERD)

The detectability of a target in the infrared spectral region is determined by differences between the radiative signatures of the target and the local background. This implies that both, the temperature difference ΔT, the emissivity difference $\Delta\varepsilon$ and the distribution of these differences over the target area and the background, are of importance. Therefore camouflage measures have to address both issues in order to achieve maximum signature adaptation to the background.

To determine the ability of a camouflage material to follow temperature changes in the background, measurements of camouflage and background temperatures have to be performed under a variety of meteorological conditions. Measurements of representative weather- and background conditions are needed to determine those situations, where the camouflage material effectively reduces the target signature. The degree of temperature reduction depends on the required level of protection, that is for detection, recognition and identification. Statistical analyses are given for various camouflage materials in relation to a number of background elements. Camouflage effectiveness is expressed in the percentage of time for which the apparent temperature contrast between the camouflage material and a background element is 1°C, 2°C or 5°C. Analyses are performed for five consecutive weeks of measurements in the spring, the summer and the winter, using data which were taken during a measurement campaign at Gilze Rijen air force base in 1990.

The work was carried out in the framework of contract A90KL656.

rapport no. : FEL-93-A043
titel : Experimentele evaluatie van de effectiviteit van camouflage in het thermische infrarood

auteur(s) : Dr.ir. P.A.M. Jacobs
instituut : Fysisch en Elektronisch Laboratorium TNO

datum : maart 1993
hdo-opdr.no. : A90KL656
no. in iwp '93 : 715.5

Onderzoek uitgevoerd o.l.v. :
Onderzoek uitgevoerd door : Dr.ir. P.A.M. Jacobs

SAMENVATTING (ONGERUBRICEERD)

In het thermisch infrarood wordt de detectiekans van een object bepaald door verschillen in de stralingssignatuur van het object en de lokale achtergrond. Dit betekent dat zowel het temperatuur-contrast ΔT, het emissie contrast $\Delta\varepsilon$ als de verdeling van deze contrasten over doel en achtergrond van belang zijn. Daarom moeten beide criteria door camouflage maatregelen zodanig worden beïnvloed, dat een maximale signatuuraanpassing met de achtergrond wordt verkregen.

Om te bepalen of een camouflage materiaal temperatuurswisselingen in de achtergrond kan volgen, moeten metingen over lange perioden worden uitgevoerd. Hierbij moeten uit representatieve weers- en achtergrondsmetingen dié situaties worden bepaald waarin het camouflage materiaal een effectieve temperatuur reductie geeft. De mate van reductie wordt bepaald door het vereiste beschermingsniveau (detectie, herkenning, identificatie). Statistische temperatuursverdelingen worden gegeven voor verschillende camouflage materialen in relatie tot een aantal achtergrond elementen. Camouflage effecitiviteit wordt berekend als een percentage van een tijdperiode waarin het schijnbare temperatuurcontrast tussen een camouflage materiaal en een achtergrond element 1°C, 2°C of 5°C bedraagt. Analyses worden uitgevoerd voor vijf aaneensluitende weken in het voorjaar, de zomer en de winter, waarbij gebruik is gemaakt van data die tijdens een meetcampagne op de luchtmacht basis Gilze Rijen in 1990 verzameld zijn.

Het werk is uitgevoerd in het kader van opdracht A90KL656.

TABLE OF CONTENTS

1 INTRODUCTION

The success of the use of infrared (IR) equipment to locate an object in a background, is determined by system performance, atmospheric propagation and the intrinsic radiation contrast between the object and the background.
In relation to the background signature, detection radiance contrast and the distribution of these contrasts (grey levels) in the background (clutter).
To prevent targets from being detected or recognized at an early stage (at far range), the target signature can be manipulated by camouflage measures in such a way that it adapts better to the local background.
For camouflage measures to be effective in the thermal infrared, two conditions have to be fulfilled:

Temperature similarity

The camouflage measure must shift the range of apparent temperatures on the target within, or at least to be very close to, the temperature envelope of the background. Since in many occasions, targets are warmer than the background, this means that camouflage measures most of the time have to reduce target temperatures.

Spatial similarity

The shape of the camouflage measures has to be such, that the resulting temperature distribution over the target is similar to that of the local background. In practice this means that camouflage measures also have to create thermal patterns on the target.
Camouflage requirements are determined by the threat for a specific target. This threat, generally can be differentiated into (aided) human perception and/or missile seeker algorithms. Furthermore, the level of camouflage depends on the desired degree of protection, that is for detection, recognition or identification. In the detection phase the target normally is not more than a (warm) spot in the background, while in the recognition and identification phase, more target details are required. For detection, for instance, camouflage measures should emphasise the adjustment of the average target signature (temperature similarity), combined with shape distortion. For recognition, however, camouflage measures have to adjust the target signature in more detail to the background clutter (spatial similarity).

Therefore camouflage effectiveness should also be expressed in terms of a reduction of the detection and/or recognition range. These ranges are determined by observer experiments (photo simulations) or by seeker calculations. Operational models are then used to convert these ranges to battle related parameters, like the kill probability.

The first step, however, to determine the potential of a material to be an effective camouflage measure, is to determine the dynamics of the apparent surface temperature under the most prevailing weather conditions in relation to the dynamics of the most likely backgrounds under the same weather conditions.

The temperature of the camouflage measures has to be studied in relation to the thermal behaviour of the various background elements, like grass, trees, soil, etc.. Backgrounds are difficult to model due to their very complex geometrical structure and by the fact that the mathematical description for some physical processes, which exist in a vegetation layer, are not yet accurate enough.

This also is the problem when modelling light weight (small thermal mass) and textured camouflage materials, like nets and thermal screens, which are very sensitive to small variations in some input parameters. Models can be used to evaluate the general trend of the temperature behaviour of prototype camouflage measures. Especially, models are very helpful to determine the effect of material properties on the apparent temperature and to define optimum values.

The great advantage of measurements over calculations is the fact that the desired quantity, i.e. the apparent emittance or the apparent temperature of a background element is measured directly in relation to the prevailing weather conditions. Ideally, the signatures of targets, camouflage measures and backgrounds are measured simultaneously under various conditions and over long periods of time.

The lack of background information often has been treated as of little importance by assuming that the apparent temperature of vegetation is about ambient air temperature. This might be one of the reasons that, although scattered measurements have been carried out [1], not much systematic efforts have been put in this area in the past. Figure 1.1 shows the measured apparent temperatures of some background elements in relation to the air temperature for a summer day in August. The measurements clearly show that, especially on mid day, the temperature deviations from the air temperature are remarkable. Moreover, due to differences in the heat capacity of the various background elements, each element shows a specific time lag with the air temperature.

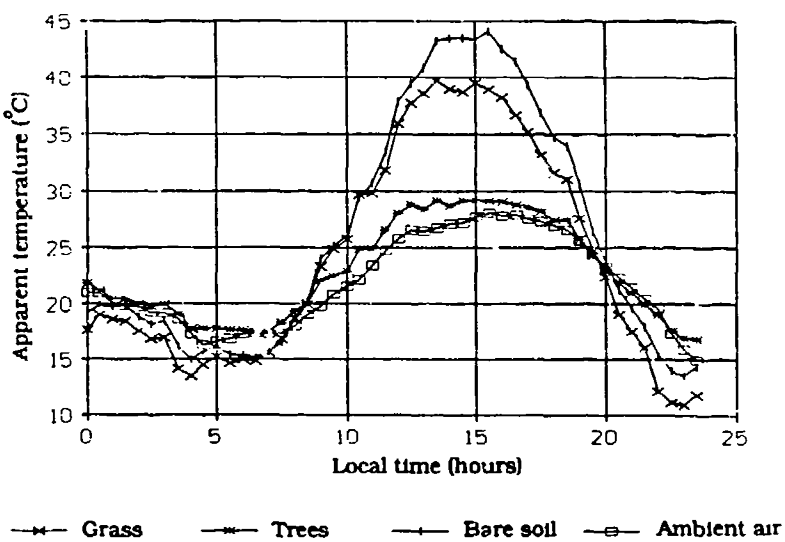

Fig. 1.1: Comparison between the air temperature and the apparent temperature of some background elements in the summer

2 DATA COLLECTION

To evaluate the thermal behaviour, camouflage measures of a number of prototype materials were installed in a measurement facility at Gilze Rijen Air force base and were measured simultaneously with a large number of background elements. The camouflage measures which were used are shown in figure 2.1. In spite of the fact that there were no targets behind the camouflage measures, a direct comparison between camouflage- and background temperatures still is very useful. The materials can be described as follows:

a A green carpet type material (Danish texture mat)

b A black version of the same texture mat

c Black-grey tar paper

d A conventional camouflage net*)

e A camouflage net, sprayed with a Low Emissivity Paint (LEP) with an emissivity of $\varepsilon = 0.75$**)

f A grey coloured LEP ($e = 0.60$) on concrete**)

*) the nets were applied horizontally ±50 cm above a grass area

**) in both 3-5 and 8-12 μm

The CARABAS radiometer [2] autonomously and automatically measures the selected elements every preset time interval. Two external black body sources, positioned at 1m from the entrance pupil, are incorporated in the measurement cycle to check system performance continuously.

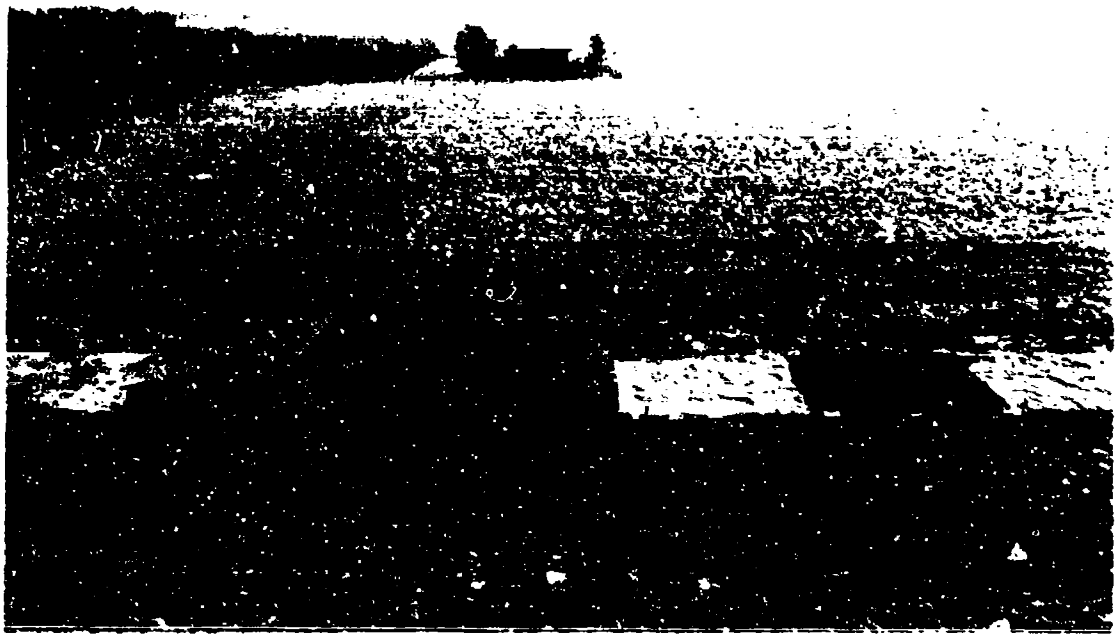

Fig. 2.1: Camouflage materials in place at Gilze Rijen AFB

The following background elements were measured in conjunction with the camouflage materials:

1 different types of grass
2 deciduous trees at various orientations and at different ranges, 2-7m in height having different type of foliage and leaf density
3 coniferous trees, 4m height at ±100m range
4 agricultural field (seasonal plant growing)
5 bare soil (ploughed rough surface)
6 concrete surface
7 Water surface (small pond, 1m depth)
8 Up- and down hill slopes (bare soil and grass covered). North and South facing

At regular intervals, the physical condition of most background elements, was recorded, like height, emission coefficient and possible mud/snow coverage. Figure 2.2 gives an impression of the type and variety of background elements which are found at the Gilze-Rijen site (51°3'N, 5°5'E). The photograph of the measuring facility is taken in the summer of 1990. The radiometer is placed on an elevated platform (7m in height), next to measurement cabin. A synoptic weather station is placed south-east of the cabin at ±50m. The camouflage materials are laid out over the grass area due east of the platform. The grey area on the concrete, North of the cabin is the LEP.

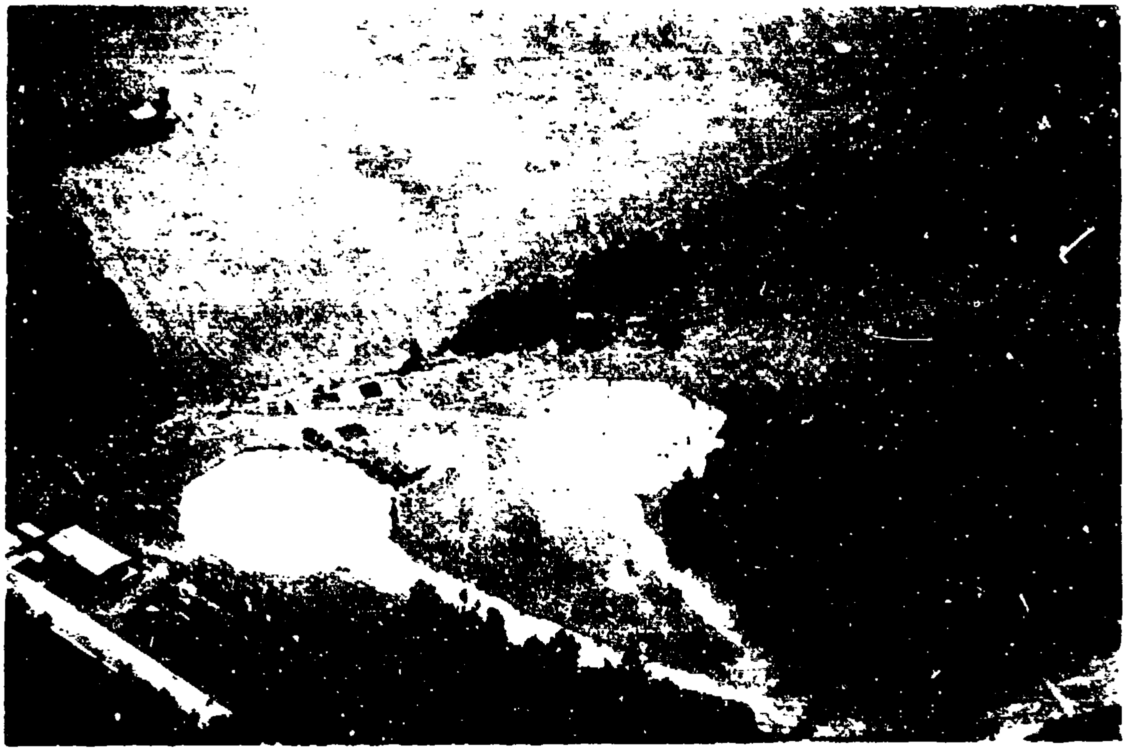

Fig. 2.2: Aerial photograph of the site at Gilze-Rijen AFB

3 DATA ANALYSES AND RESULTS

Since camouflage materials only can have a limited number of characteristics, designed, for instance, for winter/summer, desert/woodland, rural/urban conditions, its physical properties, like colour, temperature and texture, have to be based on statistics.

The measurement campaign at Gilze-Rijen produced a database of apparent temperatures of 25 background elements and camouflage materials, taken at 15 min interval over more than a full year. The tested camouflage samples were prototype materials. Since no real targets were available the materials were laid on grass and therefore the temperature behaviour of the materials is a induced by environmental influences only. Table 3.1 gives an example of the format of the data as it has been stored on disk.

TARGET CODE		DATE		SHORT DESCRIPTION			ELEVATION		AZIMUTH	
02818319158		13-08-1990		GRASS			HORIZONTAL		315°	
TIME	T_3 °C	T_8 °C	T_a °C	RH %	ϑ_g W m^{-2}	ϑ_p W m^{-2}	v m s^{-1}	Φ_v (°)	PR mm	p hPa
00:30	18.7	19.5	20.6	83.3	0.0	392.9	2.2	27.7	0.0	1011.5
00:45	18.6	19.0	20.3	86.7	0.0	398.5	1.3	32.4	0.0	1011.3
01:00	18.0	18.7	19.9	89.2	0.0	391.3	1.5	28.6	0.0	1011.2
01:15	18.1	19.0	19.8	91.3	0.0	393.1	1.6	16.5	0.0	1011.0
01:30	17.6	18.3	19.8	92.1	0.0	396.2	1.5	8.9	0.0	1011.0
01:45	17.4	18.2	19.8	92.5	0.0	389.0	1.4	43.8	0.0	1011.1
02:00	16.8	17.3	19.1	93.1	0.0	389.7	1.3	20.3	0.0	1010.6

T_3, T_8 : Apparent temperature in 3-5 resp. 8-12mm
T_a : Air temperature
RH : Relative humidity
ϑ_g : Global irradiance
ϑ_p : Longwave sky irradiance

v : Wind speed
Φ_v : Wind direction
PR : Precipitation
p : Atmospheric pressure

Table 3.1: Database example of collected background data

3.1 Temporal behaviour

The temporal behaviour of background and camouflage temperatures is needed to study camouflage performance under specific weather conditions. Figure 3.1 through figure 3.3 show the measured apparent temperatures (in 8-12μm) of various background elements in relation to some camouflage materials on two days in December, in April and resp. in August 1990.

In winter time, generally, the temperatures of background elements and camouflage materials group closely together. This is due to the fact that vegetation behaves like 'dead' material in winter time and therefore is not different than other materials with constant physical properties, like camouflage materials.

The effect of the low emission coefficient of the camouflage net is spectacular (very negative apparent temperature) during the clear night of 16 December. The temperature curve of LEP quite often shows negative peaks, resulting from a continuous changing cloud cover. This unpredictable performance of LEP, makes it very difficult to define a suitable emission coefficient.

In spring time the temperature of vegetated surfaces start to separate from non-vegetated surfaces. Concrete starts picking up heat during day time, and due to its big heat capacity, remains the warmest surface during night time.

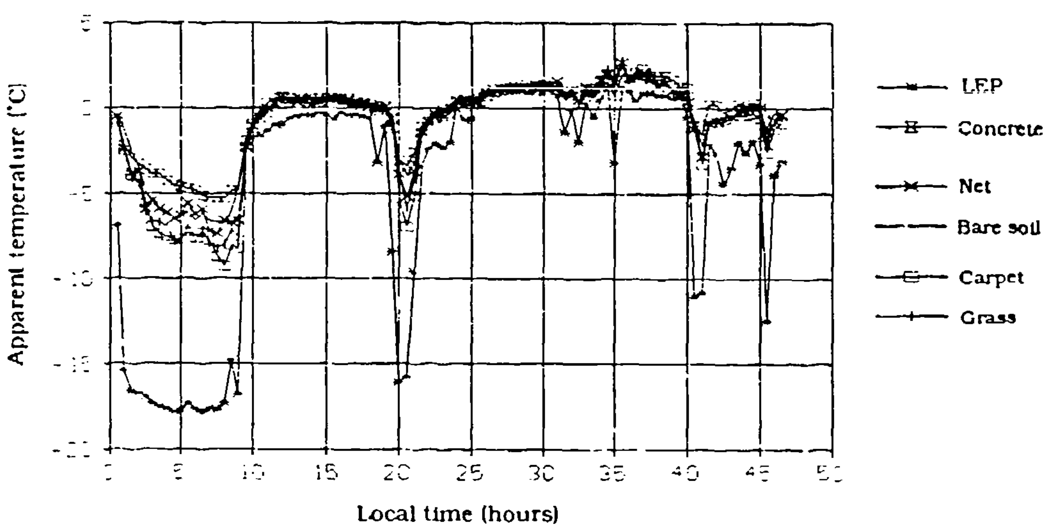

Fig. 3.1: Temperature of various items and on 16 and 17 December 1990

Due its small heat capacity, the texture mat also gets very hot, but it cools down much more during night time. The LEP stays on the low side.

In summer time, during sunny conditions, the temperature differences become very large, for instance, the difference between the net and the carpet exceeds 25°C!, at 15:00 hours on August 13.

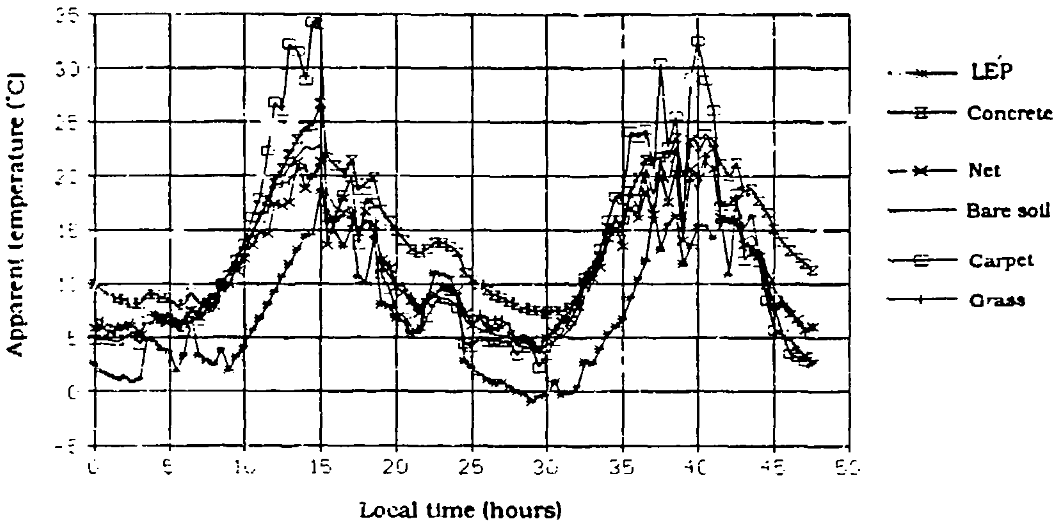

Fig. 3.2: Temperature of various items on 24 and 25 April 1990

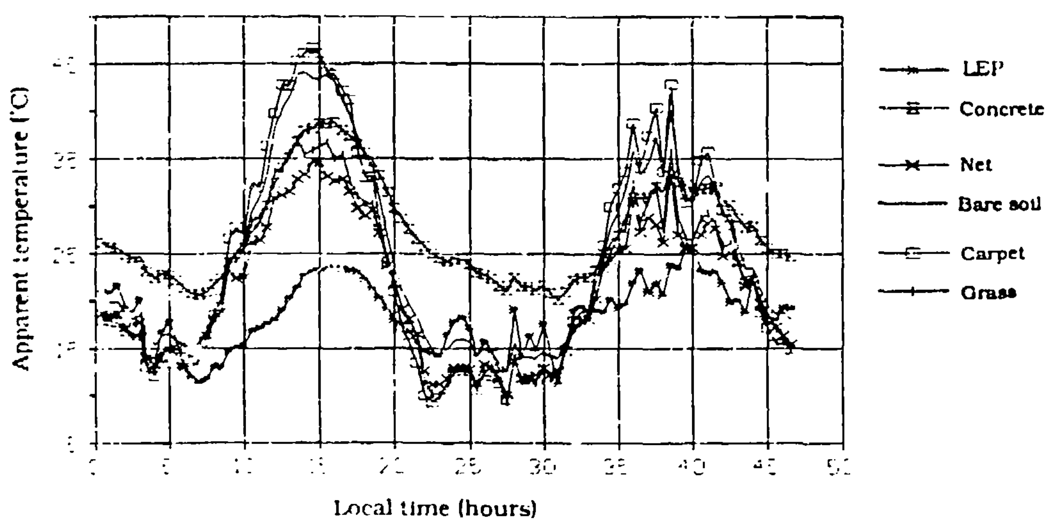

Fig. 3.3: Temperature of various items on 13 and 14 August 1990

The LEP is too low in day time, but during night time is stays relative warm. This is caused by the fact that the temperature reduction by the LEP is compensated for by the high concrete surface temperature.

3.2 Temperature statistics

Before a search through the database is made, the time period (season) and the desired weather conditions are defined, like wind- and/or sunlit, dry conditions and a given limit for the solar irradiance $100 < Q_{sun} < 200$ (W m^{-2}). Then, the database is searched and at every event where the selected and actual weather conditions do match, the apparent temperatures of all selected elements are stored. This way, the thermal behaviour during specific weather conditions as well as statistical analyses over longer periods of time can be studied.

For the statistical analyses, three time periods are used, being 19 April - 28 May, 19 July - 28 August and 10 November - 19 December 1990. These periods should be representative for spring, summer and a fall/winter season in NW Europe.
Table 3.2 through table 3.4 show the average apparent temperature and RMS variance of some background elements for these periods.
The RMS variance σ is calculated as:

$$\sigma = \left[\frac{1}{N} \sum_{i=1}^{N} (T_i - T_m)^2 \right]^{0.5}$$

T_i : Momentary temperature (°C)
T_m : Average temperature (°C)
N : Total number of measurements

The tables show that in winter time the temperatures of the background elements are quite close. The trees are colder than the air temperature because, since leaves are missing, part of the measurement area on the trees is filled with sky background. During day time in summer the temperature spreading is more pronounced and materials with a large thermal mass, like concrete, remain warm during night time.

	DAY TIME				NIGHT TIME			
	3 - 5μm		8 - 12μm		3 - 5μm		8 - 12μm	
Element	T_m	σ	T_m	σ	T_m	σ	T_m	σ
Grass	19.4	8.3	19.9	8.5	5.9	4.1	6.1	4.3
Concrete	22.0	7.8	20.5	7.3	12.7	3.8	11.7	3.9
Soil	20.0	9.5	19.7	9.8	6.4	3.2	6.2	3.7
Trees (S)	17.9	5.0	17.8	4.8	8.4	3.2	8.6	3.3
Trees (NE)	17.6	6.0	17.1	5.5	8.5	3.3	8.6	3.3
		T_m	σ			T_m	σ	
air temperature		14.4	7.4			7.3	3.9	

T_m and σ in °C

Table 3.2: Average background and air temperatures during the spring period

	DAY TIME				NIGHT TIME			
	3 - 5μm		8 - 12μm		3 - 5μm		8 - 12μm	
Element	T_m	σ	T_m	σ	T_m	σ	T_m	σ
Grass	25.1	9.0	25.8	9.1	12.3	4.1	13.2	4.4
Concrete	28.5	7.4	27.5	7.1	19.9	3.7	19.2	3.9
Soil	26.7	9.7	26.8	9.7	12.0	4.4	13.0	5.2
Trees (S)	24.0	5.1	24.2	5.1	14.1	3.8	14.9	4.2
Trees (NE)	20.1	5.5	20.2	5.5	14.1	3.9	14.8	4.2
		T_m	σ			T_m	σ	
air temperature		20.9	5.5			14.0	3.7	

T_m and σ in °C

Table 3.3: Average background and air temperatures during the summer period

	DAY TIME				NIGHT TIME			
	3 - 5μm		8 - 12μm		3 - 5μm		8 - 12μm	
Element	T_m	σ	T_m	σ	T_m	σ	T_m	σ
Grass	5.3	4.1	5.7	4.1	2.3	4.8	2.9	4.8
Concrete	5.0	3.9	4.8	3.9	2.8	4.1	2.9	4.1
Soil	5.1	4.1	5.4	4.0	2.4	4.7	2.9	4.8
Trees (S)	2.3	2.4	2.5	2.2	0.7	2.9	1.0	2.7
Trees (NE)	2.0	2.4	2.4	2.2	0.3	3.1	0.9	2.9
		T_m	σ			T_m	σ	
air temperature		4.8	4.0			3.0	4.4	

T_m and σ in °C

Table 3.4: Average background temperatures during the winter period

Figure 3.4 through figure 3.6 show a comparison of the temperature difference distributions (8 - 12μm) for the three periods during day and night time.

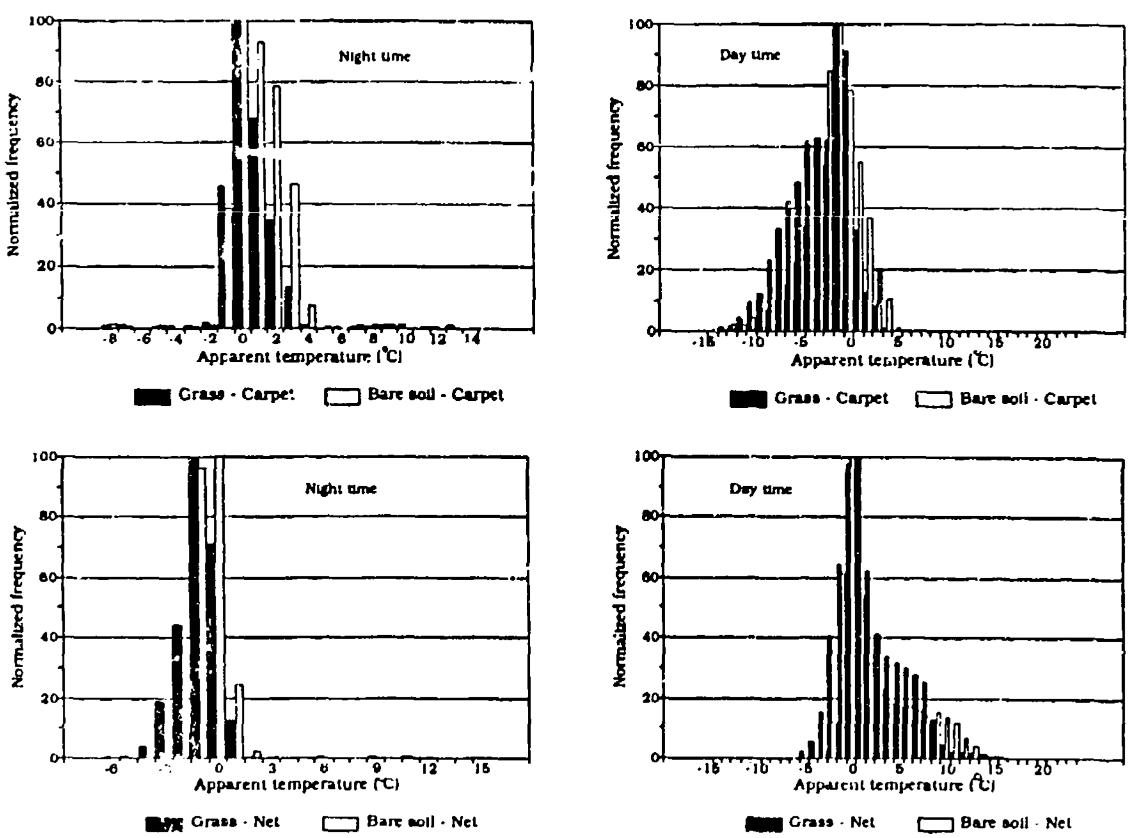

Fig. 3.4: Temperature difference distributions during day and night in spring time

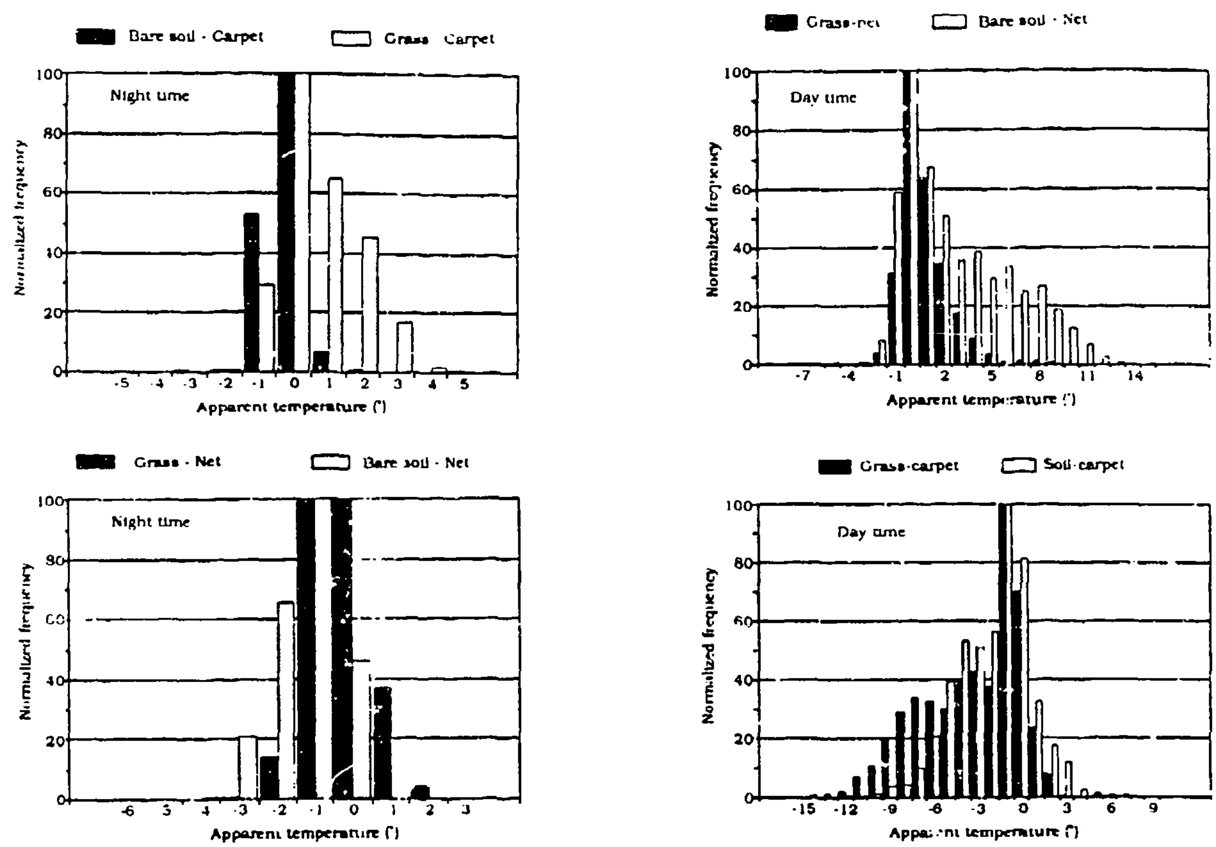

Fig. 3.5: Temperature difference distributio, s during day and night in the summer

Statistical analyses of the temperature differences between background elements them selfs and between camouflage materials and background elements, are carried out for each period. The spring is a transient period between winter and summer, in which a wide field of contrast values can occur.

The situation during the summer period is quite different from that in winter time. Due to the temperature controlling mechanism of the vegetation (by evaporation and condensation), the contrast with non-vegetated surfaces can become quite big. The distributions are very wide (20-30°C), showing a variance up to 9°C. Especially the long 'warm tail' in the distributions for the texture mat during day time in summer are noticeable, indicating that it gets much too hot.

As was to be expected, the temperature differences in the background and between the camouflage materials are very moderate in winter time, as is shown in figure 3.6.

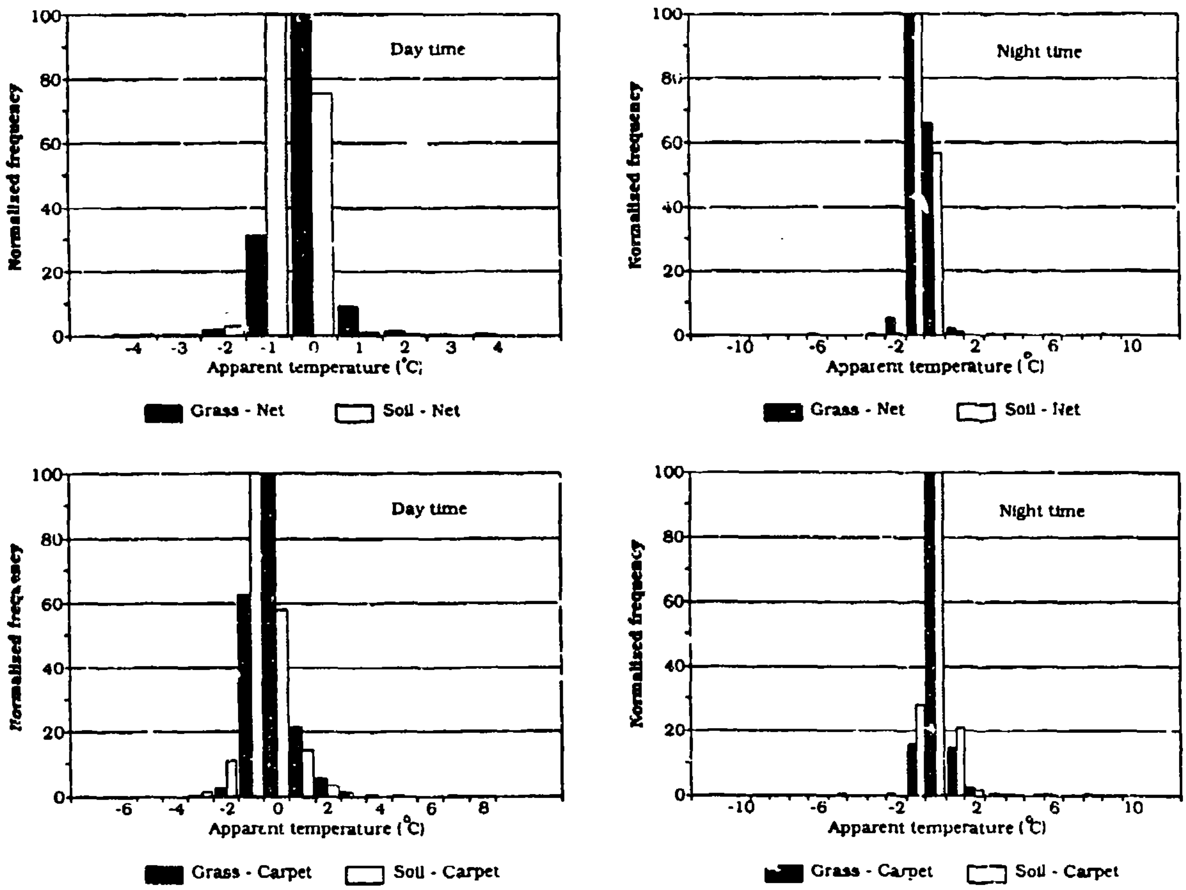

Fig. 3.6: Temperature difference distributions during day and night in the winter

Figure 3.7 shows a direct comparison of the temperature difference distributions of various items in spring and summer time and the same comparison for the summer and winter period. The figure shows that the contrast values in both spring and summer are quite similar. An exception to this is the behaviour of the net, which stays much cooler in spring time (due to the lower air temperature), while grass and soil are picking up heat during day time. The differences between summer and winter are obvious and indicate that it is, also in the infrared region, a sensible choice to split up camouflage in a winter and a summer performance.

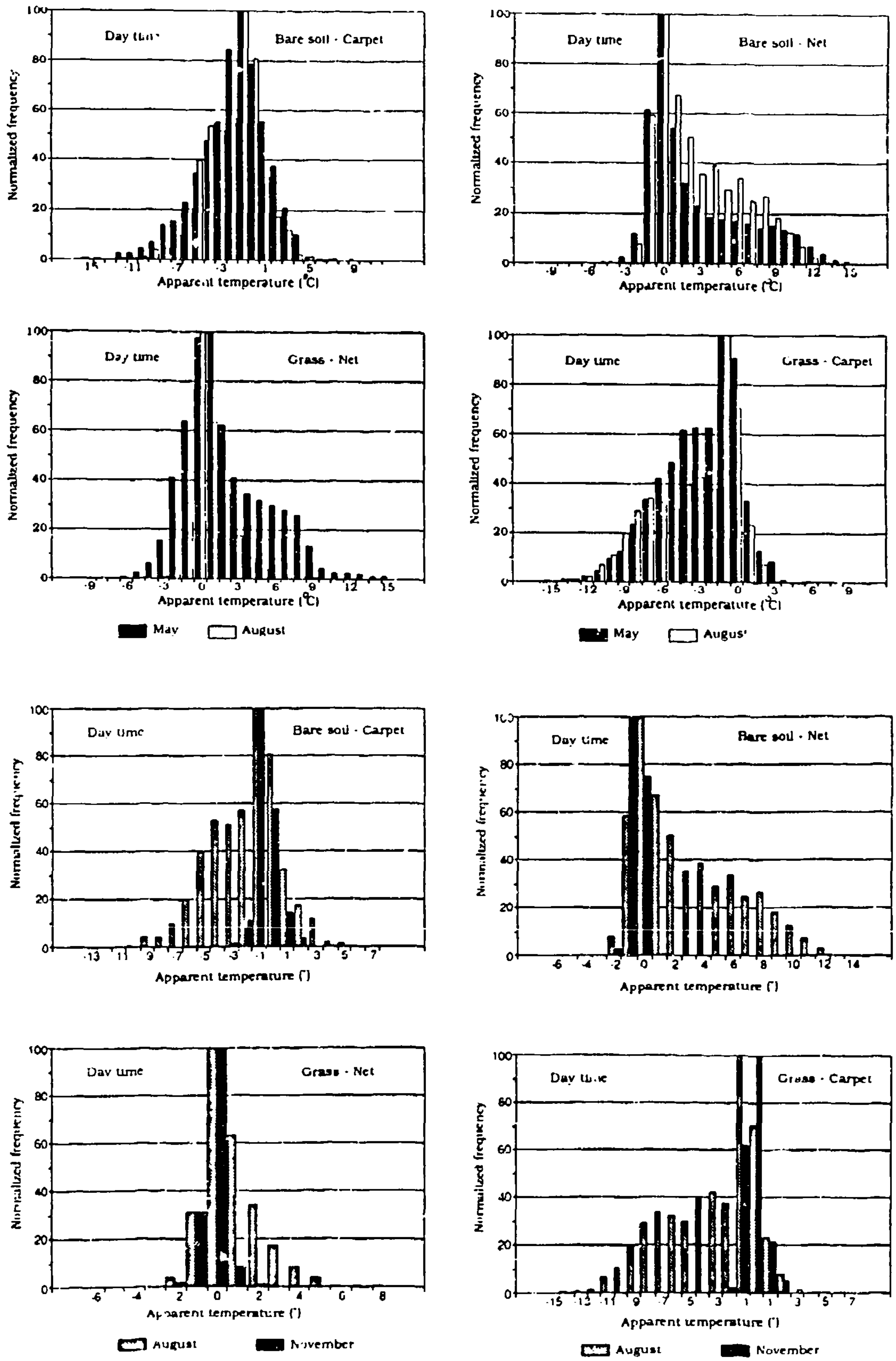

Fig. 3.7: Comparison of various temperature difference distributions

Whether a given (intrinsic) temperature contrast can be detected, depends on the performance of the IR sensor and on the atmospheric propagation in the optical path.
So, a temperature reduction by the camouflage material as such, does not mean so much and its final impact on the detection or recognition process, depends on the momentary situation.
As an example, figure 3.8 shows a comparison between the histogram of the rear view of a T62 tank and a tree line during night time. The first graph shows the comparisonduring one during one

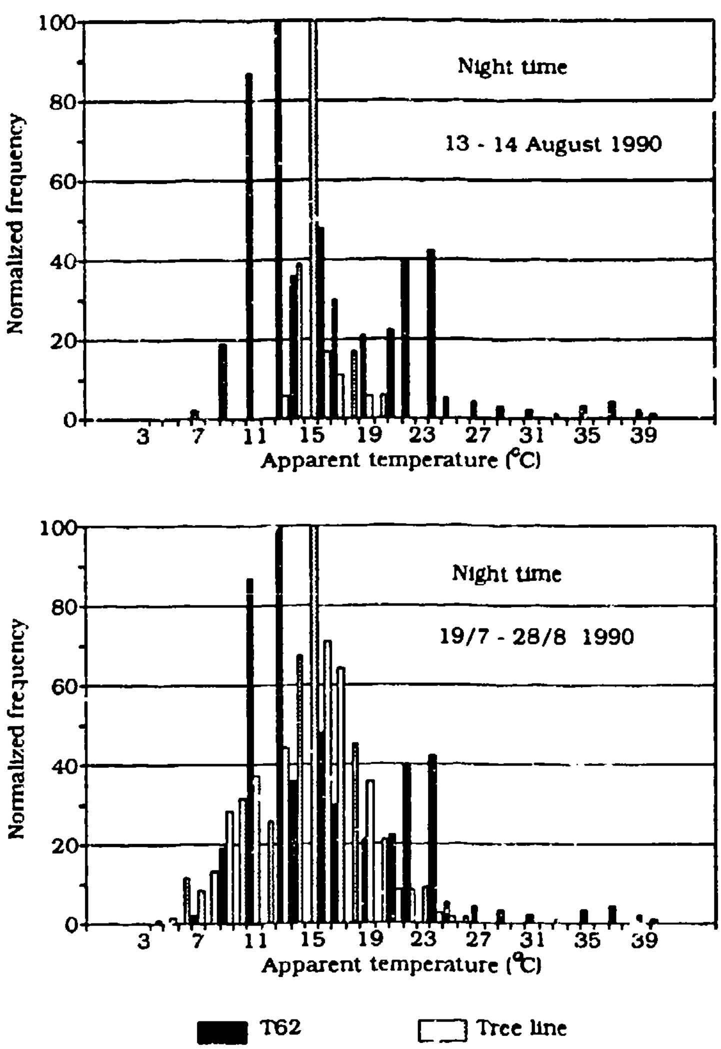

Fig. 3.8: Comparison of the distributions for a T62 tank and a tree line

single night (13-14 August), while in the second graph the comparison is made between the same tank signature and the average temperature histogram of the tree line during night time over the period from 19 July to 28 August. The histogram for the T62 is widely spread, with a tail the hot end, generated by the engine compartment, exhaust grid (idling engine) and fuel drums, mounted on the rear deck.
For the single night the situation is dramatic, but for the longer period the temperature distribution of the tree line is much wider and therefore, statistically, giving much better signature adaptation to the tank.
From a camouflage point of view this means that the characteristics of camouflage materials have to be based on the average thermal behaviour of the background during a given period of time. Especially this is true for permanent camouflage systems (construction, paints, screens etc.). Hot (exhaust grid) and cold (LEP) spots, which do not occur in a natural background scene, always present a detection or recognition clue and therefore have to be screened or put away.
Extra, add on camouflage measures can be used during specific weather and/or target conditions to give a better adaptation to the momentary weather conditions, like (detachable) screens, nets and 'cambrellas' (an umbrella made out of a net or canvas material).

In terms of a temperature contrast ΔT, the camouflage effectiveness γ can be defined as the percentage of time in which the contrast between the camouflage and a background element is smaller than a given temperature contrast ΔT_0:

$$\gamma = \frac{\{\ \Delta T \mid |\Delta T| \leq \Delta T_0\ (^{\circ}C)\ \}}{N} \times 100\%$$

N is the total number of contributing sample points

ΔT_0 is determined by the circumstances. For instance, for a target at close range, already a small value of ΔT_0 can lead to detection, while for greater ranges the temperature contrast needs to be larger, because of the atmospheric attenuation.
Calculations for γ have been performed for values of ΔT_0 of 1°C, 2°C and 5°C, during day (sunrise-sunset) and night time (sunset-sunrise) for the spring, summer and winter period. Calculations have been carried out using the apparent temperatures in both spectral regions.

To get an impression of the contrast values, which exist in a natural background scene, contrast values between a few background elements have been included also.

Table 3.5 through table 3.7 show the results, in which also the mean contrast ΔT_m and the variance σ have been incorporated.

The tables again show that during winter time the contrast values are very moderate. The contrast between the LEP and the background elements shows that the LEP has a modest negative effect (i.e. too cold) on the apparent temperature, in both spectral regions. This situation might change completely if the camouflage materials cover up a hot target. They can heat up considerably by convection from the exhaust gases and the from the compartment heater system. Because the background is rather cold, a small temperature raise will do show up the camouflage immediately. During day time in summer, there are some remarkable differences in the temperature behaviour between the two spectral bands. In the 8-12μm region the LEP gives a much lower temperature contrast with the background elements than in the 3-5μm band. This is explained by the fact that the solar reflectance in the 3-5μm region is increased by the enhanced reflectivity of the LEP ($\rho = 1 - \varepsilon$). Furthermore, the reflectance of 'cold' sky radiance is enhanced, because the atmospheric transmission coefficient in the 8-12μm is greater than in the 3-5μm region. At night time, the contrast between the concrete and the LEP seems too small (i.e. the LEP temperature is too high), but this is caused by the high surface temperature of the concrete, which largely compensates the effect of the LEP.

Expressed in a percentage of time, the contrasts in winter time are within ±2°C for almost 90% of time, that is, 31 days out of 35! (except for the LEP). In summer time the camouflage effectiveness, for both day and night, very much depends on the type of camouflage and the type of background element to which it is compared to. For instance, if concrete has to look like grass, the main camouflage effort will be to match the thermal response time of the concrete with that of the grass.

3 - 5 µm										
	DAY TIME					**NIGHT TIME**				
	Statistics		γ (%)			**Statistics**		γ (%)		
Contrast	ΔT_m	σ	1°C	2°C	5°C	ΔT_m	σ	1°C	2°C	5°C
Grass-Soil	-1.8	3.0	34	55	84	-1.0	1.8	42	73	97
Grass-Concrete	-3.9	3.3	13	27	62	-8.0	3.3	1	5	18
Trees-Grass*	+2.9	4.4	17	34	67	-3.0	2.3	15	33	79
Grass-Carpet	-3.0	3.3	26	44	71	+0.9	1.6	54	80	98
Grass-LEP	-1.4	3.0	24	48	88	-3.9	2.7	11	25	69
Grass-Net	+1.2	3.1	28	50	87	-0.6	1.7	51	80	98
Soil-Carpet	-1.2	3.1	30	53	87	+0.9	1.6	54	80	98
Soil-Net	+2.6	3.0	35	58	79	+0.4	1.0	68	93	100
Soil-LEP	+0.3	2.9	30	56	91	-2.3	2.3	23	44	87
Concrete-LEP	+2.3	2.4	25	39	85	+4.0	1.5	6	9	74
Trees-Net	-1.5	2.6	32	54	89	+2.4	1.5	17	41	95
8 - 12 µm										
Contrast	ΔT_m	σ	1°C	2°C	5°C	ΔT_m	σ	1°C	2°C	5°C
Grass-Soil	-1.3	3.0	36	59	86	-0.7	1.8	57	79	98
Grass-Concrete	-2.0	3.7	17	32	76	-6.8	3.2	4	7	28
Trees-Grass*	+3.5	4.6	18	33	63	-3.0	2.3	17	34	78
Grass-Carpet	-2.4	3.1	31	47	79	+1.0	2.0	53	79	97
Grass-LEP	+5.7	5.2	10	20	49	-0.2	3.3	19	37	89
Grass-Net	+2.6	3.4	27	50	76	-0.5	1.8	66	88	97
Soil-Carpet	-1.3	3.1	30	54	88	+1.0	2.0	53	79	97
Soil-Net	+3.2	3.9	38	54	72	+0.1	1.0	84	98	99
Soil-LEP	+6.6	5.8	12	20	44	+1.0	2.7	22	44	95
Concrete-LEP	+7.4	3.4	7	9	24	+6.5	3.2	11	15	25
Trees-Net	-0.7	2.1	142	69	97	+2.5	1.6	17	36	95

* South facing tree line, sunlit condition

Table 3.5: Camouflage effectiveness in the spring, expressed as a percentage of time γ

3 - 5 μm										
	DAY TIME					NIGHT TIME				
	Statistics		γ (%)			Statistics		γ (%)		
Contrast	ΔT_m	σ	1°C	2°C	5°C	ΔT_m	σ	1°C	2°C	5°C
Grass-Soil	-1.0	1.8	44	69	98	-0.1	1.9	61	88	96
Grass-Concrete	-2.7	3.1	17	33	77	-7.5	3.0	2	5	23
Trees-Grass*	-4.4	3.9	14	26	57	-2.2	2.1	14	35	94
Grass-Carpet	-1.6	2.4	34	56	89	+1.1	2.2	56	81	94
Grass-LEP	+1.0	3.0	24	45	89	-3.1	2.5	15	28	78
Grass-Net	+1.7	2.5	35	58	89	+0.0	1.9	69	92	96
Soil-Carpet	-0.7	2.4	36	59	96	+1.3	1.5	35	69	99
Soil-Net	+3.1	2.8	27	47	75	+0.3	1.3	66	93	99
Soil-LEP	+1.9	3.1	24	42	82	-3.2	2.2	12	29	75
Concrete-LEP	+3.8	2.2	10	24	69	+4.6	1.4	4	7	56
Trees-Net	-1.7	2.3	28	51	92	+2.4	1.6	17	41	96
8 - 12 μm										
Contrast	ΔT_m	σ	1°C	2°C	5°C	ΔT_m	σ	1°C	2°C	5°C
Grass-Soil	-0.3	1.7	54	78	99	-0.0	1.7	79	94	96
Grass-Concrete	-1.0	3.6	21	39	82	-5.9	3.3	12	16	37
Trees-Grass*	-5.0	4.1	14	26	53	-2.0	1.9	28	45	97
Grass-Carpet	-1.6	2.6	36	57	88	+1.1	2.0	47	83	96
Grass-LEP	+7.9	6.2	12	18	34	+0.6	3.1	34	57	88
Grass-Net	+2.8	3.0	36	51	77	+0.1	1.5	90	95	97
Soil-Carpet	-1.3	2.6	37	56	92	+1.3	2.2	47	69	97
Soil-Net	+3.6	3.5	29	43	67	+0.3	1.2	76	96	99
Soil-LEP	+8.6	6.5	11	17	33	+0.6	2.3	49	67	94
Concrete-LEP	+9.2	4.1	5	7	17	+6.7	4.0	15	20	32
Trees-Net	-1.0	1.9	42	65	98	+2.1	1.9	30	44	96

* South facing tree line, sunlit condition

Table 3.6: Camouflage effectiveness in the summer, expressed as a percentage of time γ

3 - 5 μm										
	DAY TIME					NIGHT TIME				
	Statistics		γ (%)			Statistics		γ (%)		
Contrast	ΔT_m	σ	1°C	2°C	5°C	ΔT_m	σ	1°C	2°C	5°C
Grass-Soil	+0.1	1.1	63	92	100	-0.1	1.3	57	88	100
Grass-Concrete	+0.3	1.3	59	88	100	-0.5	1.7	48	78	99
Trees-Grass*	+0.4	1.2	59	91	100	+1.0	1.6	43	64	100
Grass-Carpet	+0.3	1.1	64	91	100	+0.7	1.4	51	82	99
Grass-LEP	+1.4	1.8	39	70	95	+0.5	2.0	43	72	97
Grass-Net	+0.1	1.1	66	92	100	-0.1	0.4	58	87	100
Soil-Carpet	+0.2	1.2	61	91	100	+0.8	1.4	52	81	99
Soil-Net	-0.1	1.1	65	93	100	-0.0	1.3	60	89	100
Soil-LEP	+1.3	1.9	43	72	95	+0.6	1.8	47	75	98
Concrete-LEP	+1.1	1.8	46	75	96	+1.0	1.8	46	73	96
Trees-Net	+0.2	1.3	58	88	100	+1.0	1.5	46	79	100
8 - 12 μm										
Contrast	ΔT_m	σ	1°C	2°C	5°C	ΔT_m	σ	1°C	2°C	5°C
Grass-Soil	+0.3	0.6	92	99	100	-0.0	0.6	96	99	100
Grass-Concrete	+0.9	1.1	62	86	100	-0.0	1.1	68	94	100
Trees-Grass*	+0.2	0.4	97	99	100	+0.6	0.7	82	89	100
Grass-Carpet	+0.3	0.8	88	98	100	+0.5	0.7	87	98	100
Grass-LEP	+2.9	4.4	39	65	85	+2.1	4.0	48	74	85
Grass-Net	+0.2	0.6	94	99	100	-0.1	0.6	95	99	100
Soil-Carpet	-0.0	0.8	90	99	100	+0.4	1.4	85	98	100
Soil-Net	-0.1	0.3	99	100	100	+0.1	0.3	100	100	100
Soil-LEP	+2.6	4.3	49	72	86	+2.1	3.9	54	76	85
Concrete-LEP	+2.1	3.8	65	79	87	+2.1	3.9	67	79	85
Trees-Net	+0.3	0.4	91	100	100	+0.7	0.7	82	93	100

* South facing tree line, sunlit condition

Table 3.7: Camouflage effectiveness in the winter, expressed in a percentage of time γ

4 CONCLUSIONS AND RECOMMENDATIONS

The experimental quantification of the behaviour of the apparent temperature of background elements and of potential camouflage measures looks promising. Although the efforts to acquire the necessary data are quite substantial, the output of the analyses directly show the potential of a camouflage measure to adapt to the background conditions.
Temporal information can be used to study specific threat conditions, while statistical analyses give the general behaviour during a typical weather period (season).
The camouflage effectiveness percentages for the different contrast values, can directly be used to analyse sensor system performance against camouflaged targets.

To include the thermal interaction between the target and the camouflage measure, targets should be part of a follow up exercise. Especially the treatment of hot spots, like exhaust grids and power generators are of interest. If real targets are not available for longer periods, black body radiators should be used instead.

Preferably, a total camouflage concept is applied in order to determine over all camouflage efficiency, for instance by photosimulation techniques or by using seeker algorithms. This implies that next to spot radiometer data, high quality (thermal and geometrical resolution) imagery is required over statistically significant periods of time.

The study provides a strong argument to investigate the feasibility of using 'adaptive' camouflage materials or systems. A possible way is the variation of a physical property of a material in relation to the variation of the environmental conditions. For instance, coatings which change colour as a function of temperature (thermo-chromes) or electrical current (electro-chromes). The new study would largely deal with material research.
A second way is to actively control the apparent temperature [3] of a surface in such a way that, through the use of radiometers, the contrast between the surface and the local background is minimized continuously.

5 REFERENCES

1. A.E. Krusinger, "An empirical surface temperature model", US Army Corps of Engineers ETL, 1988.
2. Jacobs, P.A.M., "CARABAS, A programmable scanning radiometer for the characterization of backgrounds in the thermal infrared.", Int. J. of Remote Sensing, 13, 1992, pp 2865-2871.
3. Jacobs, P.A.M., "Target Infrared Signature Control to Reduce the Contrast with the Local Background", FEL-92-A391.

A.N. de Jong
(Group leader)

Dr. P.A.M. Jacobs
(author)

ONGERUBRICEERD

REPORT DOCUMENTATION PAGE (MOD-NL)

1. DEFENSE REPORT NUMBER (MOD-NL) TD93-0749	2. RECIPIENT'S ACCESSION NUMBER	3. PERFORMING ORGANIZATION REPORT NUMBER FEL-93-A043
4. PROJECT/TASK/WORK UNIT NO. 22173	5. CONTRACT NUMBER A90KL656	6. REPORT DATE MARCH 1993
7. NUMBER OF PAGES 27 (EXCL. RDP & DISTR.LIST)	8. NUMBER OF REFERENCES 3	9. TYPE OF REPORT AND DATES COVERED

10. TITLE AND SUBTITLE
EXPERIMENTAL EVALUATION OF CAMOUFLAGE EFFECTIVENESS IN THE THERMAL INFRARED

11. AUTHOR(S)
DR. P.A.M. JACOBS

12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
TNO PHYSICS AND ELECTRONICS LABORATORY, P.O. BOX 96864, 2509 JG THE HAGUE
OUDE WAALSDORPERWEG 63, THE HAGUE, THE NETHERLANDS

13. SPONSORING/MONITORING AGENCY NAME(S)
MOD-NL

14. SUPPLEMENTARY NOTES
ONGERUBRICEERD IS EQUIVALENT TO UNCLASSIFIED

15. ABSTRACT (MAXIMUM 200 WORDS, 1044 POSITIONS)
THE DETECTABILITY OF A TARGET IN THE INFRARED SPECTRAL REGION IS DETERMINED BY DIFFERENCES BETWEEN THE RADIATIVE SIGNATURES OF THE TARGET AND THE LOCAL BACKGROUND. THIS IMPLIES THAT BOTH, THE TEMPERATURE DIFFERENCE ΔT, THE EMISSIVITY DIFFERENCE $\Delta\varepsilon$ AND THE DISTRIBUTION OF THESE DIFFERENCES OVER THE TARGET AREA AND THE BACKGROUND, ARE OF IMPORTANCE. THEREFORE CAMOUFLAGE MEASURES HAVE TO ADDRESS BOTH ISSUES IN ORDER TO ACHIEVE MAXIMUM SIGNATURE ADAPTATION TO THE BACKGROUND. TO DETERMINE THE ABILITY OF A CAMOUFLAGE MATERIAL TO FOLLOW TEMPERATURE CHANGES IN THE BACKGROUND, MEASUREMENTS OF CAMOUFLAGE AND BACKGROUND TEMPERATURES HAVE TO BE PERFORMED UNDER A VARIETY OF METEOROLOGICAL CONDITIONS. MEASUREMENTS OF REPRESENTATIVE WEATHER AND BACKGROUND CONDITIONS ARE NEEDED TO DETERMINE THOSE SITUATIONS, WHERE THE CAMOUFLAGE MATERIAL EFFECTIVELY REDUCES THE TARGET SIGNATURE. THE DEGREE OF TEMPERATURE REDUCTION DEPENDS ON THE REQUIRED LEVEL OF PROTECTION, THAT IS FOR DETECTION, RECOGNITION AND IDENTIFICATION. STATISTICAL ANALYSES ARE GIVEN FOR VARIOUS CAMOUFLAGE MATERIALS IN RELATION TO A NUMBER OF BACKGROUND ELEMENTS. CAMOUFLAGE EFFECTIVENESS IS EXPRESSED IN THE PERCENTAGE OF TIME FOR WHICH THE APPARENT TEMPERATURE CONTRAST BETWEEN THE CAMOUFLAGE MATERIAL AND A BACKGROUND ELEMENT IS 1°C, 2°C OR 5°C. ANALYSES ARE PERFORMED FOR FIVE CONSECUTIVE WEEKS OF MEASUREMENTS IN THE SPRING, THE SUMMER AND THE WINTER, USING DATA WHICH WERE TAKEN DURING A MEASUREMENT CAMPAIGN AT GILZE RIJEN AIR FORCE BASE IN 1990.
THE WORK WAS CARRIED OUT IN THE FRAMEWORK OF CONTRACT A90KL656.

16. DESCRIPTORS	IDENTIFIERS
TARGET DETECTION INFRARED RADIATION FROM MILITARY OBJECTS CAMOUFLAGE EFFECTIVENESS	TARGET SIGNATURES

17a. SECURITY CLASSIFICATION (OF REPORT) ONGERUBRICEERD	17b. SECURITY CLASSIFICATION (OF PAGE) ONGERUBRICEERD	17c. SECURITY CLASSIFICATION (OF ABSTRACT) ONGERUBRICEERD
18. DISTRIBUTION/AVAILABILITY STATEMENT UNLIMITED		17d. SECURITY CLASSIFICATION (OF TITLES) ONGERUBRICEERD